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IT TAKES AN AURA OF THOUGHTFUL CAUTION TO DESIGN A LASER CURRENT SOURCE. A RANGE OF CIRCUITS THAT USE LINEAR AND SWITCHED-MODE TECHNIQUES SHOWS HOW.

Current sources for fiber-optic lasers: a compendium of pleasant current events

DC CURRENT IS THE POWER SOURCE for a large group of fiber-optic lasers. A current source with modulation farther along the signal path supplies laser drive. The current source, although conceptually simple, constitutes a tricky design problem. You have to consider a number of practical requirements for a fiber-optic current source, and failure to do so can destroy lasers or optical components.

A laser current source is deceptively simple in concept. Inputs include a current-output programming port, an output-current clamp, and an enable command. Laser current is the sole output. In practice, however, a laser current source must meet a number of practical and subtle requirements. The key to a successful design is a thorough understanding of individual system requirements. Various approaches suit different sets of freedoms and constraints, although all must address some basic concerns.

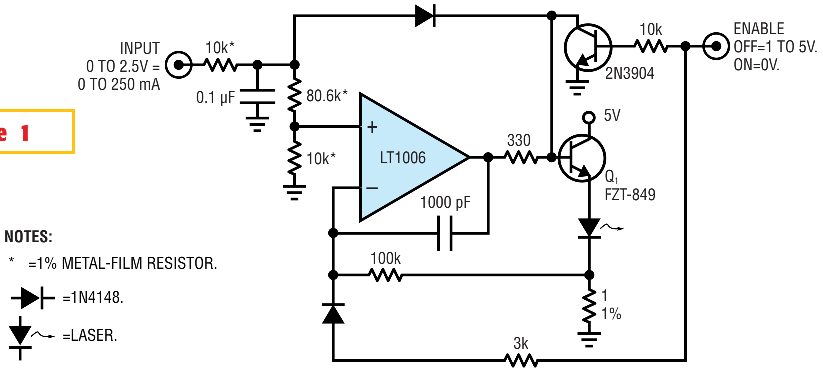
Performance and protection are the basic concerns for laser current sources. Performance issues include the current source's magnitude and stability under all conditions, output-connection restrictions, voltage compliance, efficiency, programming interface, and power requirements. Protection features are necessary to prevent laser and optical component damage. The laser, which is an expensive and delicate device, must have protection under all conditions, including supply ramp-up and -down, improper control-input commands, open or intermittent load connections, and "hot plugging."

LASER-PERFORMANCE ISSUES

The performance issues for a laser current source are as follows:

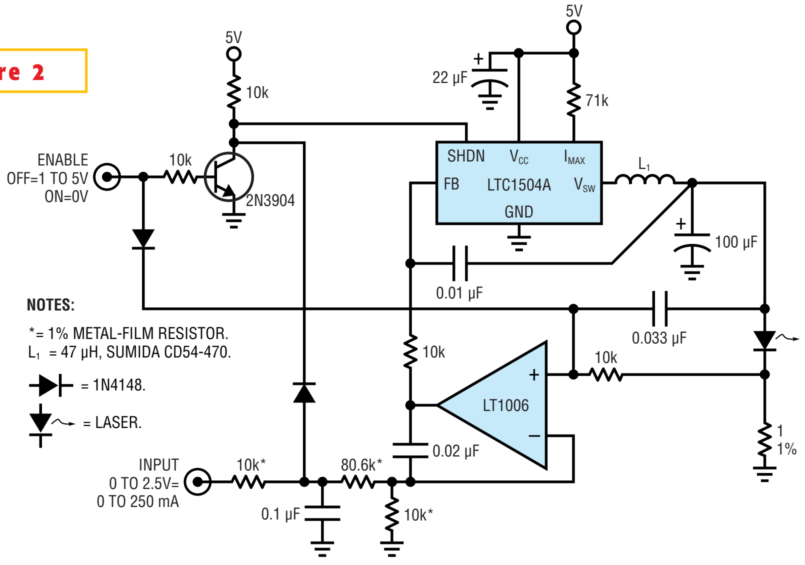
- Required power supply: The first step is to define the available power supply. A single-rail 5V supply is currently the most common and desirable. You must account for supply tolerances, which are typically ±5%. System-distribution-voltage drops may result in surprisingly low rail voltages at the point of load. Split rails are occasionally available, although they are relatively rare. Additionally, split-rail operation can complicate laser protection, particularly during supply sequencing.
- Output-current capability: Low-power lasers operate on less than 250 mA. Higher power types can require as much as 2.5A.
- Output-voltage compliance: The current source's output-voltage compliance must be able to accommodate the laser's forward-junction drop and any additional drops in the drive path. Typically, voltage compliance of 2.5V is adequate.
- Efficiency: Heat buildup in fiber-optic systems is often a concern due to space limitations. Accordingly, current-source efficiency can be an issue. Linear regulation is often adequate at low current.

Figure 1



A basic current source requires off-ground operation of the laser terminals. The amplifier controls the current by comparing the 0.1Ω shunt voltage to the input.

Figure 2



NOTES:
*= 1% METAL-FILM RESISTOR.
L$_1$ = 47 µH, SUMIDA CD54-470.
= 1N4148.
= LASER.

A switching regulator replaces Figure 1's Q_1 to provide higher efficiency.

Switching-regulator-based approaches may be necessary at high current levels.

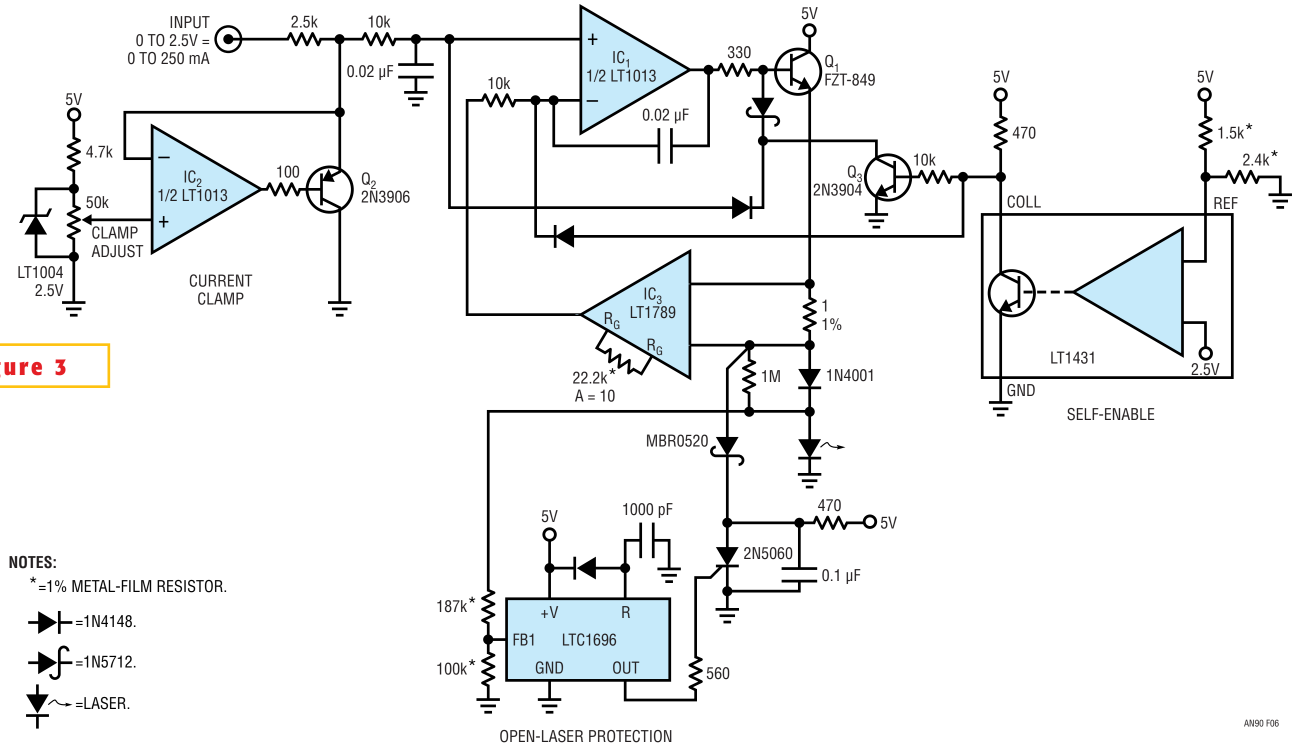
- Laser connection: In some cases, the laser may float off ground. Other applications require grounded-anode or -cathode operation. Grounding the anode seemingly mandates a negative supply, but you can retain single-rail operation by using switching-regulator techniques.
- Output-current programming: A programming-port voltage sets the output current. You can derive the voltage from a potentiometer, DAC, or filtered PWM. Typically, a range of 0 to 2.5V corresponds to a current range of 0 to 250 mA or 0 to 2.5A. Setpoint accuracy is usually within 0.5%, although you can readily achieve better tolerances.
- Stability: The current source needs good regulation against line, load, and temperature changes. Line- and load-induced variations should be within 0.05% with typical temperature drifts of 0.01%. Judicious component choice can considerably improve these figures.
- Noise: You must minimize current-source noise, which can modulate laser output. Typically, noise bandwidth to 100 MHz is of interest. A linearly regulated current source has inherently low noise and usually presents no problems. Switching-regulator-based current sources require special techniques to maintain low noise.
- Transient response: The current source does not need a fast transient response, but you cannot under any circumstances let the output overshoot the programmed current. Such overshoots can damage the laser or associated optical components.

LASER-PROTECTION ISSUES

The specifics of laser protection are as follows:

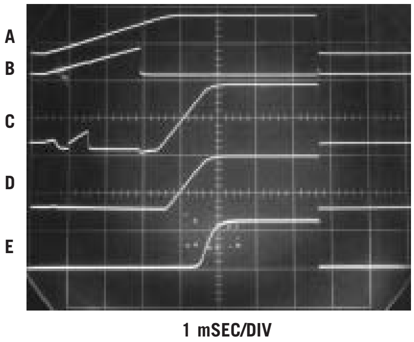
- Overshoot: Because outputs that

Figure 3



NOTES:
*=1% METAL-FILM RESISTOR.
=1N4148.
=1N5712.
=LASER.

Differential sensing of the shunt voltage allows for grounding the laser's cathode with a single supply. A self-enable feature monitors the power supply and operates when V_{SUPPLY} is 4V. Open-laser and current clamps protect the laser.



TRACE	DESCRIPTION	SCALE
A	POWER-SUPPLY VOLTAGE	5V/DIV
B	LT1431 OUTPUT	5V/DIV
C	IC_1 OUTPUT	2V/DIV
D	Q_1 EMITTER	2V/DIV
E	LASER CURRENT	50 mA/DIV

Figure 4 Power-supply start-up waveforms for Figure 3 show the 3-msec ramp on the 5V rail. The self-enable circuit prevents spurious IC_1 outputs during this period from corrupting the laser current.

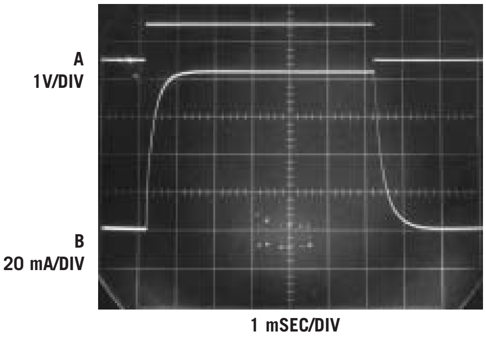


Figure 5 Figure 3's output (Trace B) responds to Trace A's input step. Trace B's laser current has controlled damping and no overshoot.

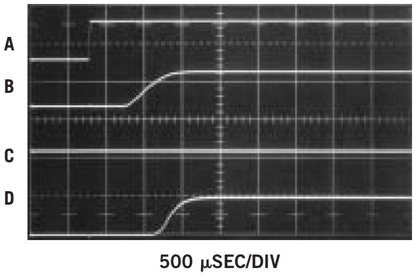
overshoot the nominal programmed current can be destructive, you must account for any possible combination of improper control-input or power-supply turn-on and -off characteristics. Also, any spurious laser current under any condition is impermissible. Portions of the current-source circuitry may have undesired and unpredictable responses during supply ramp-up and -down, complicating the design.

- Enable: An enable line allows for shutting off the current-source output. You can also use the enable line to hold off the current-output during supply ramp-up to prevent undesired outputs. This use of the enable line can be tricky because the power supply for the enable-signal circuitry may be the same supply that runs the laser. The enable signal must reliably operate independently of the power supply's turn-on profile. Optionally, the enable function can be self-contained within the current source, eliminating the necessity of generating this signal.
- Output-current clamp: The output-current clamp sets the maximum output current, overriding the output-current programming command. A potentiometer, DAC, or filtered PWM signal can set this voltage-controlled input.
- Open-laser protection: An unprotected current source's output rises to maximum voltage if you disconnect the load. This circumstance can lead to hot-plugging the laser, a potentially destructive event. Intermittent laser connections can produce similar undesirable results. The current-source output should latch off if the load disconnects. Recycling the power clears the latch but only if the load has been established.

CURRENT-SOURCE CIRCUITS

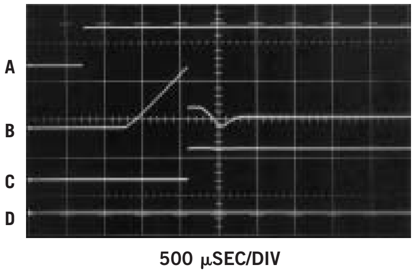
The preceding discussion dictates considerable care when designing laser-current sources. The delicate and expensive load, combined with the noted uncertainties, should promote an aura of thoughtful caution (see **sidebar** "Simulating the laser load" on the Web version of this article at www.edn.com). The following circuit examples maintain this outlook and present practical, usable circuits.

A basic laser current source supplies as much as 250 mA via Q_1 (**Figure 1**). This circuit requires that both laser terminals float. The amplifier controls laser current by maintaining the 1Ω shunt voltage at a potential that the programming input dictates. Local compensation at the amplifier stabilizes the loop, and the 0.1-μF capacitor filters input commands, ensuring that the loop never limits slew. This precaution prevents overshoot due to programming-input dynamics. The enable input turns off the current source by simultaneously grounding Q_1's base and starving the amplifier's + input while biasing the − input high. This combination also ensures that the amplifier smoothly ramps to the desired output current when the enable switches low. An external watchdog circuit that switches after the power supply is within operating limits must drive the enable input. Because the external circuitry may operate from the same supply as the current source, the enable threshold in this circuit is 1V. The 1V threshold ensures that the enable input dominates the current source's output at low supply voltages during power turn-on. This feature prevents spurious outputs due to unpredictable amplifier behavior below the minimum supply voltage.



TRACE	DESCRIPTION	SCALE
A	POWER-SUPPLY VOLTAGE	5V/DIV
B	LASER VOLTAGE	2V/DIV
C	LTC1696 OUTPUT	5V/DIV
D	LASER CURRENT	100 mA/DIV

Figure 6 Figure 3's open-laser protection does not act during normal turn-on. The LTC1696 does not exceed its overvoltage threshold, which keeps the SCR unbiased, and the laser conducts current.



TRACE	DESCRIPTION	SCALE
A	POWER-SUPPLY VOLTAGE	5V/DIV
B	LASER OUTPUT	2V/DIV
C	LTC1696 OUTPUT	5V/DIV
D	LASER CURRENT	1 mA/DIV

Figure 7 When the laser voltage exceeds the overvoltage threshold, the LTC1696 output biases the SCR, which clamps open the laser line, and no current flows.

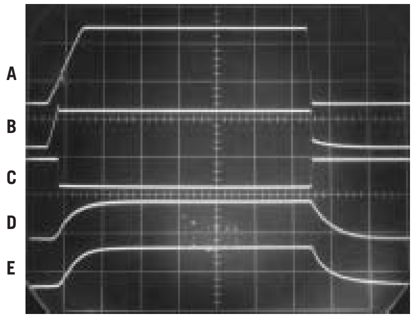
The preceding circuit uses Q_1's linear regulation to close the feedback loop. This approach offers simplicity at the expense of efficiency. Q_1's power dissipation can approach 1W under some conditions. Many applications permit this amount of power, but some situations require minimizing heat. Replacing Q_1 with a step-down switching regulator minimizes the heat (**Figure 2**). The switched-mode power delivery eliminates almost all of the transistor's heat.

This circuit is similar to **Figure 1**'s linear approach, except for the addition of the LTC1504 switching regulator. It is useful to liken the switching regulator's input, V_{CC}; feedback, FB; and output, V_{SW}; to the collector, base, and emitter, respectively, of Q_1 in **Figure 1**. This analogy reveals that two circuits have similar operating characteristics with the switched-mode version enhancing efficiency. The regulator's output LC filter introduces phase shift, necessitating attention to loop compensation. The amplifier's local roll-off is similar to that in **Figure 2**, although good loop damping requires two phase-leading ac feedback elements, the 0.01- and 0.033-µF capacitors. In all other respects, including enable and programming-input considerations, **Figure 2**'s circuit is identical to that in **Figure 1**.

GROUNDED-CATHODE OPERATION

It is sometimes necessary to tie the laser's cathode to ground. A new circuit operates from a single supply and features grounded-cathode operation (**Figure 3**). This circuit is reminiscent of **Figure 1** with a notable exception. In this case, differential amplifier IC_3 senses the voltage across a shunt in the laser anode, permitting cathode grounding. IC_2's gain-scaled output feeds back to IC_1 for loop closure. Loop-compensation and enable-input considerations are similar to the circuits in **figures 1** and **2**, and, as before, you can replace Q_1 with a switching regulator.

Three additional features allow the circuit in **Figure 3** to operate in a fully protected and self-contained fashion. The circuit monitors its power supply and "self-enables" when the supply is within limits, eliminating the enable port and external watchdog in the previous examples. A settable current clamp and open-laser protection prevent laser damage. The self-enable uses an LT1431 shunt regulator. This regulator has the highly desirable property of maintaining a predictable open-collector output when operating below its minimum supply voltage. At initial turn-on, supply voltage is 1V, the LT1431's output does not switch, and current flows to Q_3's base. Q_3 turns



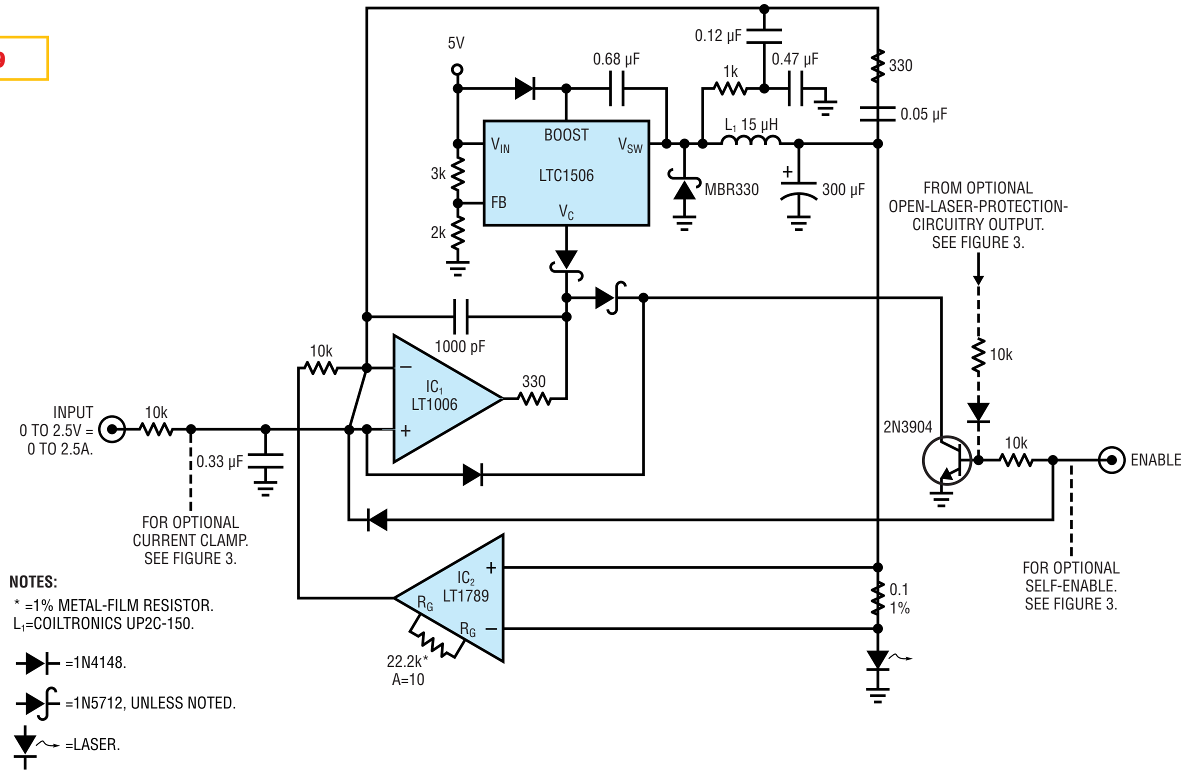
500 µSEC/DIV

TRACE	DESCRIPTION	SCALE
A	PROGRAMMING INPUT	2V/DIV
B	Q_2 EMITTER	1V/DIV
C	IC_2 OUTPUT	5V/DIV
D	IC_1 + INPUT	1V/DIV
E	LASER CURRENT	100 mA/DIV

Figure 8

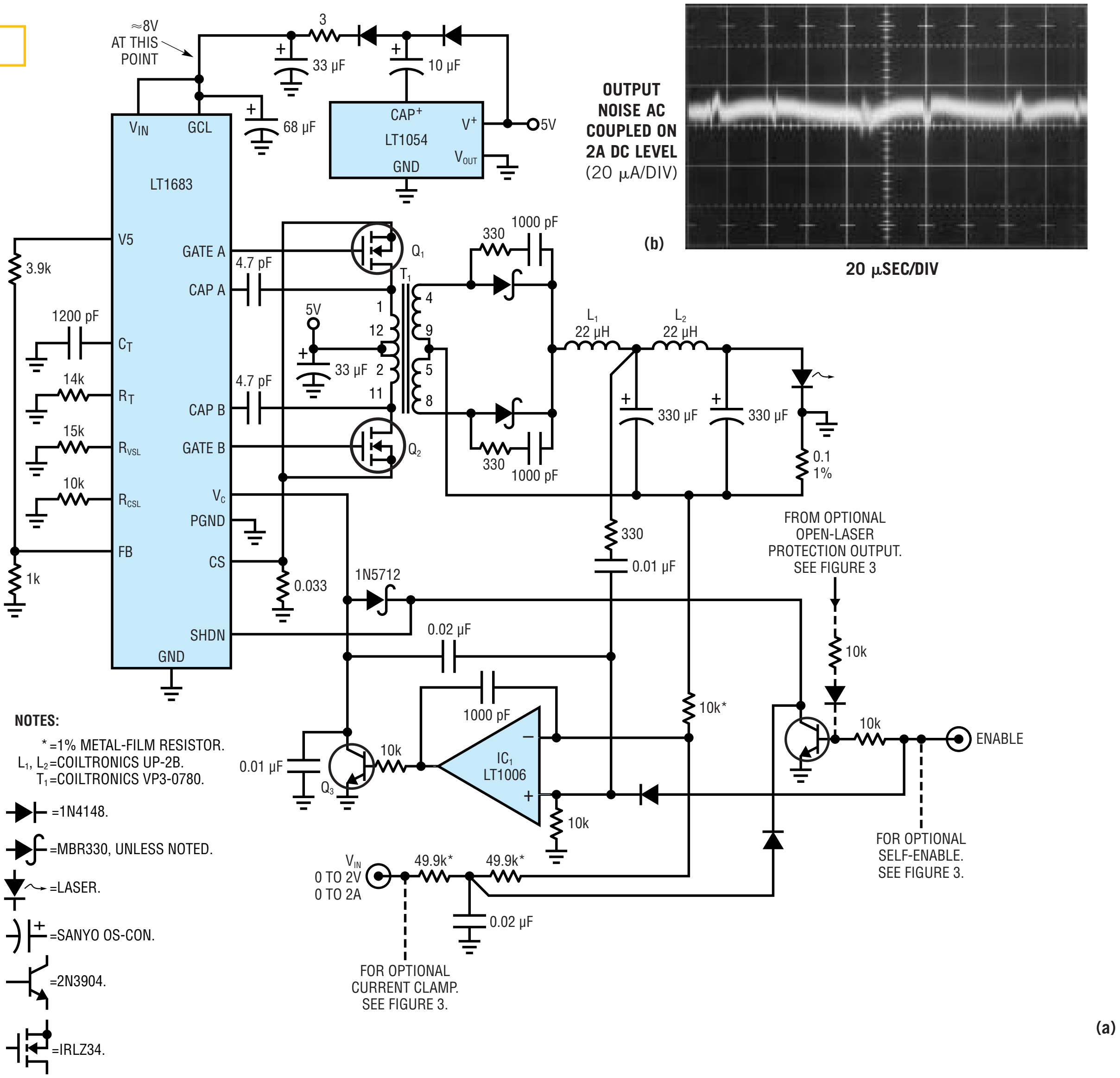
When the programming input in Figure 3 exceeds the clamp threshold, IC_2 swings abruptly, which causes Q_2's emitter to clamp. IC_1's + input remains at this clamp level, which maintains a safe amount of laser current.

Figure 9



A switched-mode version of Figure 3 provides 2.5A. Feedback-loop compensation accommodates the switching-regulator delay. Clamp, protection, and self-enable circuits are optional.

Figure 10



A 2A laser current source has a grounded-cathode output (a). Output noise measures 20 μA p-p, or approximately 0.001% (b). Coherent, identifiable components include fundamental-ripple residue and switching artifacts.

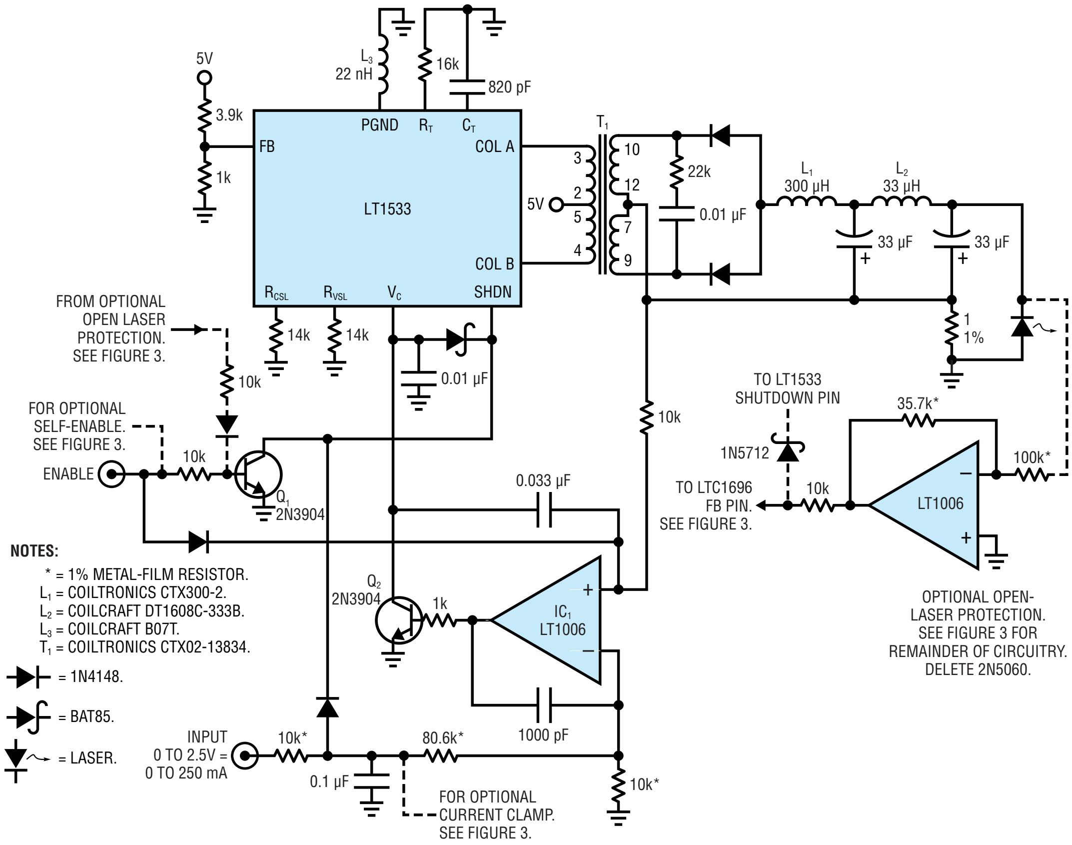
on, preventing Q_1's base from receiving bias. Additionally, this action pulls down the circuit's current-programming input, which drives IC_1's – input. This arrangement ensures that the laser cannot receive current until Q_3 turns off. Also, when Q_3 turns off, IC_1's output cleanly ramps up to the desired programmed current. The resistor values at the LT1431's reference input dictates that the device goes low when V_{SUPPLY} passes through 4V. This 4V potential ensures proper circuit operation.

Supply start-up waveforms detail these self-enable features (**Figure 4**). Trace A, the nominal 5V rail, ramps for 3 msec before arriving at 5V. During this interval, the LT1431 (Trace B) follows the ramp, biasing Q_3 on. The circuit does not control IC_1's output (Trace C) during this period. Q_1's emitter (Trace D), however, is cut off due to Q_3's conduction and cannot pass the disturbance. As a result, the laser conducts no current (Trace E) during this time. When the supply (Trace A) ramps beyond 4V (just before the photo's fourth vertical division), the LT1431 switches low (Trace B), Q_3 switches off, and the circuit self-enables. IC_1's output (Trace C) ramps up, and Q_1's emitter (Trace D) and the laser current (Trace E) are slaves to the output's movement. This action prevents any undesired current in the laser during supply turn-on, regardless of unpredictable circuit behavior at low supply voltages.

PROGRAMMING-INPUT CHANGES

You must control laser current in situations other than supply turn-on. Response to programming-input changes must be similarly well-behaved. The laser-current response (Trace B) to a programming input step shows clean damping with no hint of overshoot (Trace A, **Figure 5**). The circuit in **Figure 3** also includes open-laser protection. If the current source operates into an open load

Figure 11



A 0.0025% noise, grounded-anode laser current source outputs 250 mA.

with no laser, the source produces maximum voltage at the laser output terminals. This circumstance can lead to hot-plugging the laser, a potentially destructive event. Intermittent laser connections can produce similar undesirable results. The LTC1696 overvoltage-protection controller guards against open-laser operation. This device's output latches high when its feedback input, FB, exceeds 0.88V. This circuit biases the FB pin so that a laser output voltage greater than 2.5V forces the LTC1696 high, triggering the SCR to shunt current away from the laser. The 470Ω resistor supplies SCR holding current, and the diodes ensure that no current flows in the output.

Figure 6 details events with a properly connected laser at supply turn-on. Trace A is the supply; Trace B, the laser voltage; Trace C, the LTC1696 output, and Trace D, the laser current. The waveforms show laser voltage, Trace B, rising to about 2V at supply turn-on, Trace A. Under these normal conditions, the LTC1696 output, Trace C, stays low, and laser current, Trace D, rises to the programmed value.

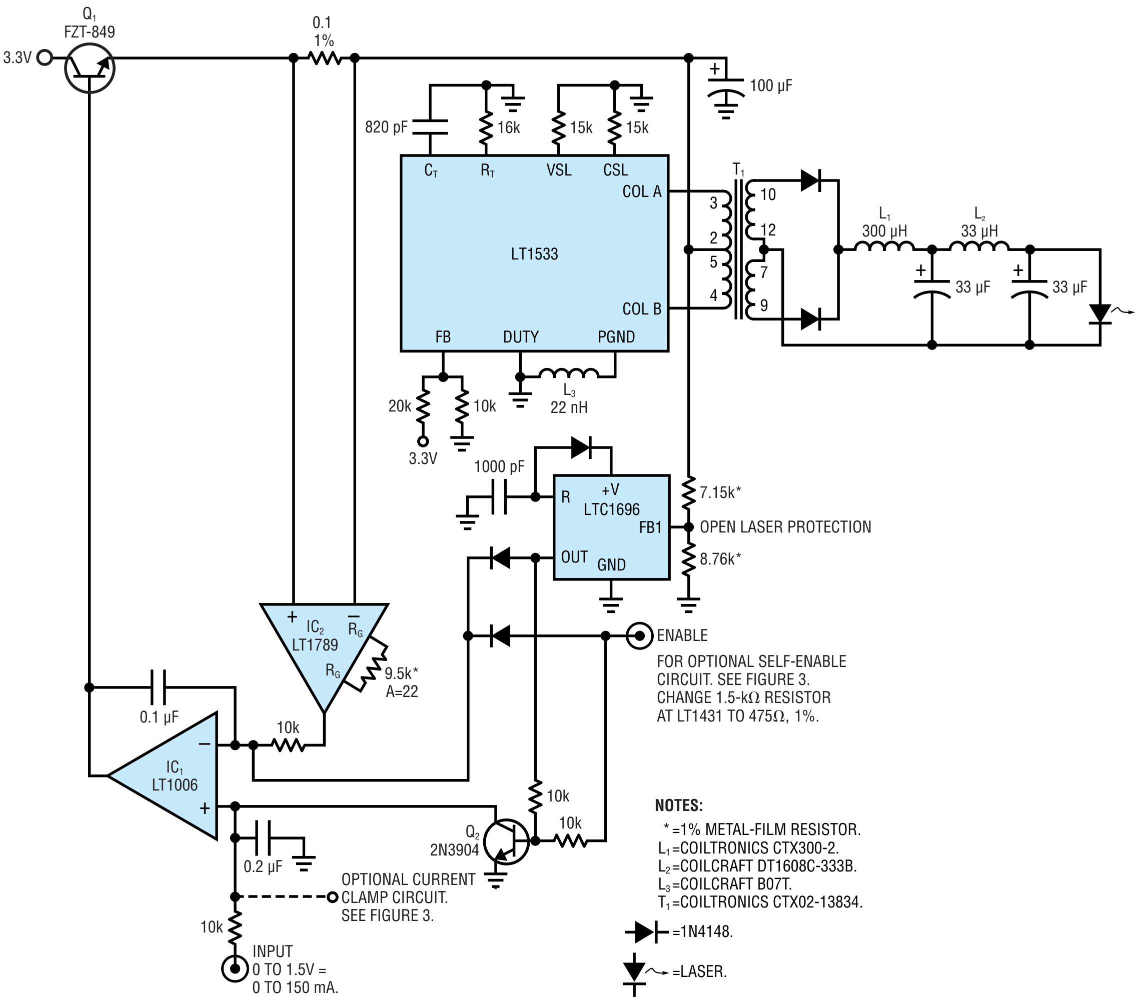
Figure 7 shows what happens when the circuit turns into an open-laser connection. Trace assignments are identical to those in **Figure 6**. At supply turn-on, Trace A, the laser voltage, Trace B, transitions beyond the 2.5V open-laser threshold. The LTC1696 output, Trace C, goes high; the SCR latches; and no current flows in the shunted laser line, Trace D. Once this event occurs, you must recycle the power to reset the LTC1696-SCR latch. If the laser has an improper connection, the circuit repeats its protective action. Open-laser protection is not restricted to turn-on. It also occurs if laser connection is lost at any time during normal circuit operation.

A final protection feature in **Figure 3** is a current clamp that prevents the transmission of uncontrolled programming inputs by clamping them to a settable level. IC$_2$, Q$_2$, and associated components form the clamp. Normally, IC$_2$'s + input is above the circuit's programming input (Q$_2$'s emitter voltage), IC$_2$'s output is high, and Q$_2$ is off. If the programming input exceeds IC$_2$'s + input level, IC$_2$ swings low, Q$_2$ comes on, and the amplifier feedback drives Q$_2$'s emitter to the clamp-adjust wiper potential. This action clamps IC$_1$'s input to the clamp-adjust setting, which prevents laser-current overdrive. Clamp action need not be fast to be effective because of IC$_1$'s 10-kΩ, 0.02-μF input filter. **Figure 8**'s traces show clamp response to programming-input overdrive. When the programming input, Trace A, exceeds the clamp's preset level, Q$_2$'s emitter Trace B, does the same, causing IC$_2$'s output, Trace C, to swing down. IC$_2$ feedback controls Q$_2$'s emitter to the clamp level, arresting the voltage applied to the 10-kΩ, 0.02-μF filter. The filter bandlimits the abrupt clamp operation, resulting in a smooth corner at IC$_1$'s positive input, Trace D. IC$_1$'s clamped input dictates a similarly shaped and clamped laser current, Trace E. The clamp remains active until the programming input falls below the clamp-adjust setting.

GROUNDED-CATHODE SOURCE PROVIDES 2.5A

The circuit in **Figure 9**, which stems from those in **figures 2** and **3**, provides as much as 2.5A to a grounded-cathode

Figure 12



A switched-mode, low-noise current source has a floating output, which permits you to ground the laser's anode or cathode.

laser. IC_1 is the control amplifier, the LT1506 switching regulator efficiently delivers output current, and IC_2 senses laser current via a 0.1Ω shunt resistor. Loop operation is similar to that in **figures 2** and **3** with IC_2 providing dc feedback to IC_1. Frequency compensation differs from that in the previous **figures**. The circuit achieves stable loop operation using a local roll-off at IC_1, augmented by two lead networks associated with L_1. Feeding back a lightly filtered (1-kΩ, 0.47-µF) version of the LT1506's V_{SW} pin's output activity provides midband lead. High-frequency lead compensation, arriving via the 330Ω, 0.05-µF pair, optimizes edge response. The circuit in **Figure 9** uses the externally controlled enable function, although you can also use **Figure 3**'s self-enable feature. Similarly, you can also employ **Figure 3**'s current clamp and open-laser protection in this circuit.

This circuit's switched-mode energy delivery provides high efficiency at high power, but output noise may be an issue. Residual harmonic content related to switching-regulator operation appears in the laser current. The resultant low-level modulation of laser output may be troublesome in some applications. Approximately 800 µA p-p of switching-regulator-related noise (0.05%) appears in the 2A laser-current output. This disturbance comprises fundamental ripple and switching-transition-related harmonics.

LOWER THE NOISE TO 0.001%

A 0.05% noise content suits many optical-system applications. More stringent requirements benefit from extremely low-noise content. A grounded-cathode, 2A circuit uses special switching- regulator techniques to attain only 20 µA p-p noise, which is approximately 0.001% (**Figure 10a**). The circuit substantially reduces the noise by limiting edge-switching speed in the regulator's power stage (**Reference 1**). The LT1683 pulse-width modulator controls the voltage and current rise times in switches Q_1 and Q_2. The LT1683's output stage operates Q_1 and Q_2 in local loops that sense and control their edge times. The circuit feeds back transistor-voltage information using the 4.7-pF capacitors and derives and feeds back current status from the 0.033Ω shunt resistor. This arrangement permits the PWM-control IC to fix transistor-switching times, regardless of power-supply or load changes. The R_{VSL} and R_{CSL} resistors associated with the LT1683 controller set the transition rates. In practice, you set these resistor values by adjusting them to minimize output noise. The remainder of the circuit forms a grounded-cathode laser-current source.

Q_1 and Q_2 drive T_1, and LC sections filter the rectified output. Because T_1's secondary winding floats, the laser cathode and the 0.1Ω shunt resistor are at circuit ground. The shunt returns to T_1's secondary center tap, completing a laser-current-flow path. This arrangement produces a negative voltage that corresponds to laser current at the shunt's ungrounded end. The circuit resistively sums this potential at IC_1 with the positive-voltage current-programming-input information. IC_1's output controls the LT1683's pulse-width drives to Q_1 and Q_2 via Q_3, closing a loop to set laser current. The circuit sets loop compensation using bandlimiting at IC_1 and Q_3's collector, aided by a single-lead network arriving from the L_1-L_2 junction.

Some circuit details merit attention. An LT1054-based voltage multiplier feeds the LT1683's supply-input pins. This boosted voltage provides enough gate drive to ensure Q_1-Q_2 saturation. Damper networks across T_1's rectifiers minimize diode-switching-related events in the output current. This circuit is compatible with the self-enable and laser-protection features of the previous circuits. Appropriate connection points appear in the **figure**.

The speed-controlled switching times result in a spectacular decrease in noise to just 20 μA p-p, or approximately 0.001% of the 2A-dc laser current (**Figure 10b**). Fundamental ripple residue and switching artifacts are visible against the measurement noise floor. Reliable wideband current-noise measurement at these levels requires special techniques (see **sidebar** "Verifying switching-regulator-related noise" in the Web version of this article at www.edn.com).

GROUND THE ANODE, AND KEEP NOISE LOW

The circuit in **Figure 11** is similar to that in **Figure 10** and uses edge-time control to achieve an exceptionally low-noise output of 0.0025%. This circuit is intended for lower power lasers that require grounded-anode operation. The LT1533, a version of the previous circuit's LT1683, has internal power switches. These switches drive T_1. T_1's rectified and filtered secondary produces a negative output that biases the laser. The laser's anode connects to ground, and the 1Ω shunt resistor completes the current path to T_1's secondary winding. This configuration makes T_1's center tap voltage positive and proportional to laser current. IC_1 compares this voltage to the current programming input. IC_1 biases Q_2, closing a loop around the LT1533. Local bandwidth limiting at IC_1 and Q_2's collector damping and feedback capacitors provide loop compensation.

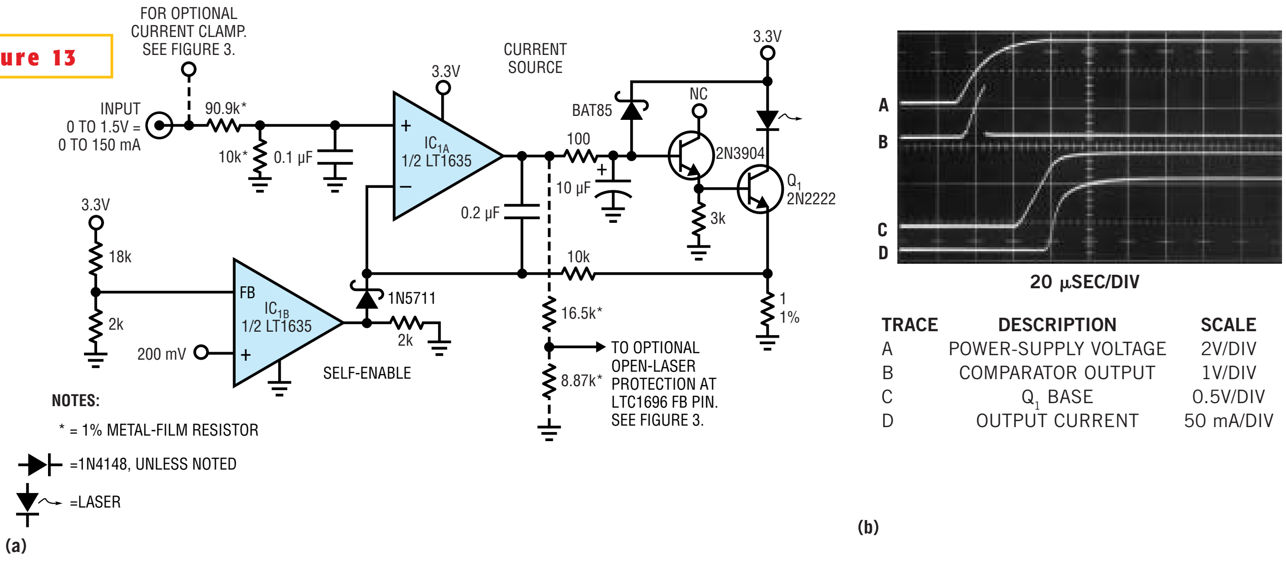
This circuit's 2.5 μA p-p noise qualifies it for the most demanding applications. Residual switching-related noise approaches the measurement noise floor. The enable function operates as previously described. Additionally, this circuit is compatible with **Figure 3**'s self-enable and laser-protection accessory circuits. The **figure** shows the changes that the grounded-anode operation necessitates.

FLOAT THE OUTPUT

Figure 12 retains **Figure 11**'s low noise but also has a fully floating output. You can ground either laser terminal without affecting circuit operation. The circuit realizes this feature by using feedback to control the transformer's primary current and by relying on interwinding coupling to maintain regulation (**references 2**, **3**, and **4**). This coupling varies slightly with operating point, limiting the output-current regulation to approximately 1%.

The schematic shows the LT1533 low-noise switching regulator driving T_1. The circuit forces the LT1533 to run at a 50% duty cycle by grounding the duty pin. The LT1533 retains its controlled edge-time characteristics. Current flows through Q_1 and the 0.1Ω shunt resistor into T_1's primary winding. The LT1533's open-collector power outputs alternately chop primary current to ground. Q_1's bias sets the primary-current magnitude and, hence, the 0.1Ω shunt voltage. IC_1's output, which represents the difference between the output-current-programming input and IC_2's amplified version of the shunt voltage, sets Q_1's bias. This loop enforces a shunt voltage that's proportional to the value of the current-programming input. In this way, the current-programming input sets T_1's primary current, which determines T_1's secondary current through the laser. Differen-

Figure 13



TRACE	DESCRIPTION	SCALE
A	POWER-SUPPLY VOLTAGE	2V/DIV
B	COMPARATOR OUTPUT	1V/DIV
C	Q_1 BASE	0.5V/DIV
D	OUTPUT CURRENT	50 mA/DIV

This circuit commits the laser's anode to the supply voltage and features inherent self-enabled operation (a). The output current is off until the supply voltage ramps past 2V, the self-enable comparator operates above 1.2V, and biasing at Q_1's base prevents outputs below 1.2V (b).

tial amplifier IC_2's gain-setting resistor calibrates the current-programming input's scaling.

The primary-side feedback's lack of global feedback mandates a current-regulation compromise. A plot of laser current versus programming input voltage shows 1% conformance over nearly the entire range. Some error below 10 mA exists due to nonideal transformer behavior, but this error is normally insignificant because it is below the typical laser-threshold current. Line regulation, which the sensing scheme also degrades, still is approximately 0.05%/V. Similarly, load regulation, over a 1 to 1.8V compliance voltage, is typically 2%.

This circuit's floating output complicates including the laser-protection and self-enable features of **Figure 3**. Biasing the LTC1696 from T_1's center tap accomplishes open-laser protection. If the laser opens, the loop forces a marked rise at T_1's center tap, latching the LTC1696's output high. This action skews IC_1's inputs, sending its output low and shutting off Q_1. All T_1 drive ceases. Because the LTC1696 output latches, you must recycle the power to reset the circuit. If you haven't connected the laser, the latch acts again, protecting the laser from hot-plugging or intermittent connections. You can add the self-enable and current-clamp options in accordance with the notations on the schematic.

CONNECT ANODE TO POSITIVE SUPPLY

Figure 13a's current source is useful for applications that commit the laser anode to the power supply. IC_{1A} senses Q_1's emitter and closes a loop that forces constant current in the laser. Local compensation at IC_1 and input bandlimiting stabilize the loop. This circuit also includes an inherent self-enable feature. The LT1635 operates at supply voltages as low as 1.2V. At voltages higher than 1.2V, the LT1635's comparator-configured section, IC_{1B}, holds off circuit output until the supply voltage reaches 2V. Below 1.2V supply, Q_1's base biasing prevents unwanted outputs. The slew-retarded input and loop compensation yield a clean dynamic response with no overshoot. As the **figure** shows, you can again include current-clamping and open-laser-protection options. Additionally, higher output current is possible at increased supply voltages, although you must respect Q_1's dissipation limits.

Figure 13b details operation during supply turn-on. At supply ramp-up (Trace A), output current (Trace D) is disabled. When the supply reaches 2V, IC_{1B} (Trace B) goes low, permitting IC_{1A}'s output (Trace C) to rise. This action biases Q_1, and laser current flows (Trace D). The LT1635 operates on supply voltages as low as 1.2V. Below this level, the circuit prevents spurious outputs using junction stacking and bandlimiting at Q_1's base. Q_1's base components also prevent unwanted outputs when the supply rises rapidly. Such rapid rise could cause uncontrolled IC_{1A} outputs before the amplifier and its feedback loop are established.□

AUTHOR'S BIOGRAPHY

Jim Williams, staff scientist at Linear Technology Corp (Milpitas, CA), specializes in analog-circuit and instrumentation design. He has served in similar capacities at National Semiconductor, Arthur D Little, and the Instrumentation Laboratory at the Massachusetts Institute of Technology (Cambridge, MA). A former student at Wayne State University (Detroit), Williams enjoys art, collecting antique scientific instruments, and restoring old Tektronix oscilloscopes.

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SIMULATING THE LASER LOAD

Fiber-optic lasers form a delicate, unforgiving, and expensive load. Thus, breadboarding with these devices has a high likelihood of catastrophe. A much wiser alternative is to simulate the laser load using either diodes or electronic equivalents.

Lasers look like junctions with typical forward voltages of 1.2 to 2.5V. The simplest way to simulate a laser is to stack appropriate numbers of diodes in series. **Tables A** and **B** list typical junction voltages at various currents for two popular diode types. The MR750 is suitable for currents in the ampere range, and the 1N4148 serves well at lower currents. Typically, stacking two to three diodes allows you to simulate the laser in a given current range. Diode-voltage tolerances and variations due to temperature and current changes limit accuracy, although results are generally satisfactory.

Figure A depicts a laser-load simulator powered by a 9V battery. This simulator eliminates diode-load junction-voltage drop uncertainty. Additionally, you can conveniently set any desired "junction-dope" voltage with the indicated potentiometer. Electronic feedback enforces establishment and maintenance of calibrated junction-drop equivalents.

The potentiometer sets a voltage at amplifier IC_1's negative input. IC_1 responds by biasing Q_1. Q_1's drain voltage controls Q_2's base and, hence, Q_2's emitter potential. The circuit feeds Q_2's emitter back to IC_1, closing a loop around the amplifier. This loop forces the voltage across Q_2 to equal the potentiometer's output voltage under all conditions. The capacitors at IC_1 and Q_1 stabilize the loop, and Q_2's base resistor and ferrite bead suppress parasitic oscillation. The 1N5400 prevents Q_1-Q_2 reverse biasing if you reverse the load terminals.

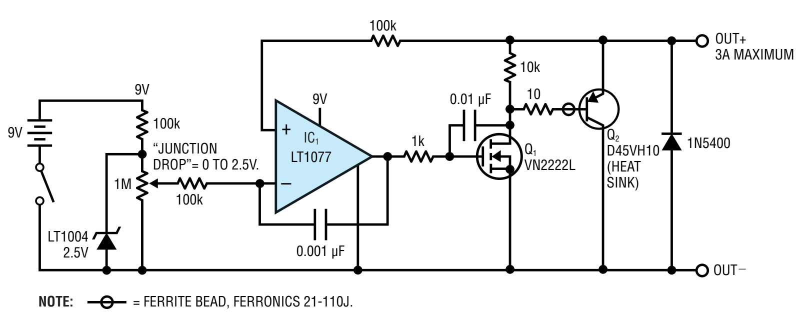

Figure A A floating, battery-powered laser simulator sets the desired junction drop across the output terminals. Amplifier feedback controls Q_2's V_{CE} according to the potentiometer voltage.

TABLE A–CHARACTERISTICS OF MR750 DIODE AT 25°C

Typical junction current (A)	Typical junction voltage (V)
0.5	0.68
1.0	0.76
1.5	0.84
2.0	0.9
2.5	0.95

TABLE B–CHARACTERISTICS OF 1N4148 DIODE AT 25°C

Current probe	Amplifier	Noise floor (100-MHz bandwidth, µA)	Comments
Tektronix P6022 (1 mV/mA)	Preamble 1855 (1 MΩ)	100	Split core is convenient to use, but sensitivity is low, resulting in relatively high overall noise floor.
Tektronix CT-1 mV/mA)	Hewlett-Packard 461A (50Ω)	15	This probe's higher gain accounts for most of the noise-floor reduction. The 50Ω amplifier provides some additional benefit. A close-core probe requires a breaking conductor to make a measurement.

VERIFYING SWITCHING-REGULATOR-RELATED NOISE

Measuring the low switching-regulator-related current noise levels in these laser-current circuits requires care. The microamp amplitudes and wide bandwidth of interest (100 MHz) mandates strict attention to measurement technique. In theory, simply measuring the voltage drop across a shunt resistor permits you to determine the current. In practice, the resultant small voltages and required high-frequency fidelity pose problems. Coaxial probing techniques are applicable, but probe-grounding requirements become severe. The slightest incidence of multiple ground paths—ground loops—corrupt the measurement, rendering observed results meaningless. Differentially configured coaxial probes offer some relief from ground-loop-based difficulties, but there is an inherently better approach.

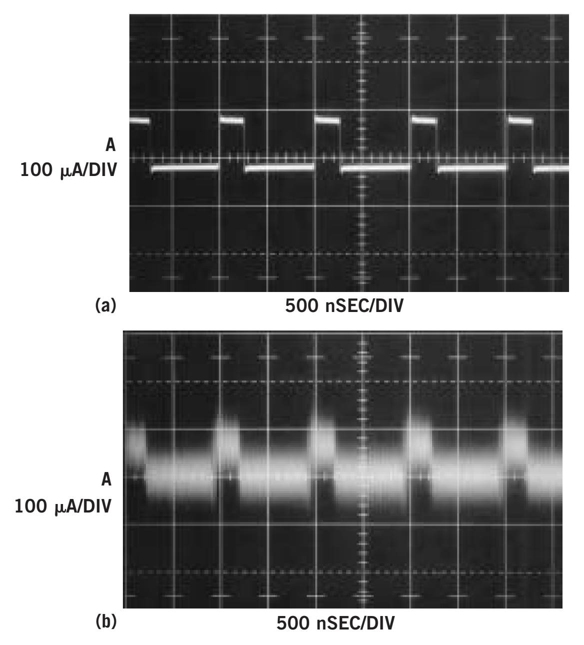

Figure A The CT-1/HP-461A combination clearly displays a 100-µA pulse train (a). The noise floor causes the slight trace thickening. The P6022/Preamble 1855 presentation shows degraded signal-to-noise performance (b).

Current transformers, or probes, offer an attractive way to measure noise and eliminate probe-grounding concerns. A current probe's minimally invasive nature eases connection parasitics, enhancing measurement fidelity. Two types of current probes are available: split core and closed core. The split-core clip-on types are convenient to use but have relatively low gain and a higher noise floor than closed-core types. The closed-core transformer's gain and noise-floor advantages are particularly attractive for wideband, low-current measurement.

Combinations of current probes and amplifiers provide varying degrees of performance and convenience. **Table A** summarizes characteristics for two probes and applicable amplifiers. In general, the construction of the convenient split-core types compromises their noise-floor uncertainties. The closed-core probes are quieter, and some types have inherently higher gain, which is a distinct advantage. A laboratory-based comparison is revealing.

The CT-1 closed-core probe and the HP461A amplifier combination respond to a 100-µA pulsed input with a clearly outlined waveform (**Figure Aa**). The pulse's top- and bottom-trace thickening derives from the noise floor. With the same input, the split-core P6022 and Preamble 1855 combination has much greater noise (**Figure Ab**). The decreased performance is due almost entirely to the split-core probe's construction.

Note that Hall-element stabilized current probes, such as the Tektronix AM503 and P6042, are unsuitable for low-level measurement. The Hall-device-based flux-nulling loop extends the probe's response to dc but introduces approximately 300 μA of noise.

A test setup allows investigation of the closed-core transformer's capabilities (**Figure Ba**). A defined pulse is the input to the test setup in the **figure**, but in real use you may need to use a specialized external trigger probe for these measurements (**Reference A**). The specified transformer has flat gain over a wide bandwidth, a well-shielded enclosure, and a coaxial 50Ω output connection. The 5-mV/mA output feeds a low-noise ×100, 50Ω input amplifier. An oscilloscope with a high-sensitivity plug-in monitors the amplifier's terminated output. A 1V pulse driving a known resistor value, R, provides a simple way to source calibrated current into the transformer.

If R=10 kΩ, the resultant pulsed current is 100 μA. The waveform is crisp and essentially noise-free, and it agrees with predicted amplitude. More sensitive measurement involves determining the test setup's noise floor. Measurements taken with no current flowing in the transformer indicate a noise limit of approximately 10 μA p-p. Most of this noise is due to the ×100 amplifier. If R=100 kΩ, the pulsed current level is 10 μA, and the scope-photo trace indicates a 10-μA amplitude (**Figure Bb**).

TABLE A–CURRENT-PROBE-AMPLIFIER COMBINATIONS

Typical junction current (A)	Typical junction voltage (V)
0.1	0.83
0.2	0.96
0.3	1.08

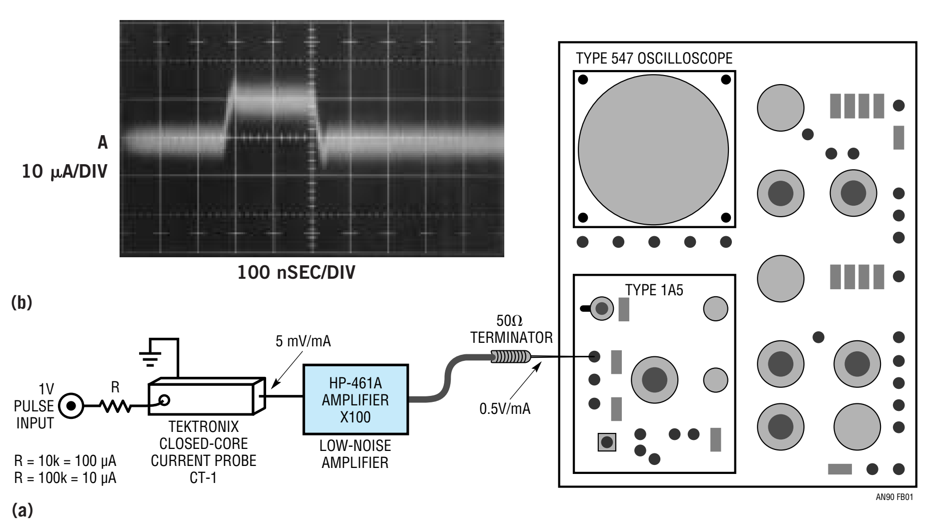

Figure B Noise-measurement instrumentation includes resistors, a closed-core current probe, a low-noise wideband amplifier, and an oscilloscope (a). A 10-μA input pulse produces a calibrated and readily discernible output (b).

These measurement exercises and level of agreement determine the test setup's gain and noise performance. This information provides the confidence necessary to make a meaningful low-level current measurement.

Reference

A. Hewlett-Packard Co, *Model 6181C Current Source Operating and Service Manual*, 1975.